

3 CLEAR AIR TURBULENCE AND METHODS OF DETECTION 4

by

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## RESEARCH OBJECTIVES

This is the final report for NASA Grant NGR 44-012-048 submitted in accordance with the requirements of the grant, which covered the period April 1, 1966 through November 30, 1967. 9

The research objectives of the grant were to study the nature of clear air turbulence and methods for its detection. The various phases of this research are as follows:

1. A review of available literature on the situations under which CAT occurs and the nature of the turbulent energy spectra observed or postulated.
2. An evaluation of the probable refractive index structure associated with CAT from the turbulence studies in 1.
3. A theoretical study of backscattering cross-section associated with the CAT refractive index structure discussed in 2 and with refractive index variations in general.
4. The measurement of refractive index differences at low levels and the comparison of these data with theoretical predictions.
5. Evaluation of the possibility of radar return from inhomogeneities in the atmosphere.

## RESEARCH RESULTS

The work under the grant has been well documented in status reports, technical reports, and in publications in technical journals. It is felt that the research under the grant is thoroughly covered by these publications and can best be described by reference to them.

### Progress Reports

"Clear-Air Turbulence and Methods of Detection," First Semi-Annual Report, September 30, 1966. Prepared under Grant NGR 44-012-048.

"Clear-Air Turbulence and Methods of Detection," Second Semi-Annual Report, March 31, 1967. Prepared under Grant NGR 44-012-048.

### Laboratory Reports

J. J. Stephens and E. R. Reiter, "Estimating Refractive Index Spectra in Regions of Clear-Air Turbulence," Report No. P-12, Antennas and Propagation Division, Electrical Engineering Research Laboratory, The University of Texas, 5 October 1966, 44 pages.

### Conclusions

As suggested by the cumulative distribution shown in Fig. 1 and the summary shown in Table 2, clear-air turbulence patches average from 500 to 3000 feet in depth and one-half have horizontal dimensions less than 20 miles.

Clear-air turbulence occurs preferentially on the boundaries of shallow, thermally-stable baroclinic zones in the vicinity of the jet stream. The average percentage frequency in the jet stream vicinity is shown in Fig. 2. A schematic presentation of the variation with flow curvature is given in Fig. 4. These indicate a preference for occurrence on the cyclone side of the jet core and topographic effects may enhance these frequencies.

The refractive index spectrum for scales in the inertial subrange in the presence of clear-air turbulence can be expressed in terms of the

mechanical energy. For stable stratification, the dependence suggested by Tatarski may be used to provide consistent estimates.

The refractive index spectral estimates for dry air fluctuations made here are less than those found by other investigators (for example, Tatarski, Atlas et al.) by more than 10 db. Since the scattering at any angle is directly proportional to the spectral amplitude, the radar return will be correspondingly less than previous estimates.

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B. M. Fannin, "Remote Detection of Clear Air Turbulence - Pulse Microwave Radar," Report No. P-13, Antennas and Propagation Division, Electrical Engineering Research Laboratory, The University of Texas, 1 November 1966, 27 pages.

#### Conclusions

Calculations are reported for the expected mean returned power from clear-air turbulence, relative to the minimum detectable level, with the chosen values of the many contributing parameters carefully noted and discussed. It is found that operational systems for normal jet flights, constrained by reasonable limits on weight, size, power, cost, etc., are not feasible. On the other hand, research-type ground-based systems should be capable of reliable detection of regions of CAT for wavelengths from a few centimeters to a few meters. However, not only was near-the-state-of-the-art performance assumed for the ground-based systems, but favorable conditions generally were assumed, including pointing at the zenith, a cloudless sky, pointing away from the galactic plane, etc.

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J. L. Dodd, A. W. Straiton, A. P. Deam, "A Study of Some Characteristics of Atmospheric Refractive Index Differences," Report No. P-15, Antennas and Propagation Division, Electrical Engineering Research Laboratory, The University of Texas, 15 May 1967, 133 pages.

#### Abstract

Atmospheric refractive index differences were measured during the summer and fall of 1966 at The University of Texas' Electrical Engineering Research Laboratory. These measurements were analyzed for spectra content and amplitude distributions by using an SDS-930 digital computer.

Variations of refractive index at a single point were also measured. The ratio of refractive index difference spectra to spectra at a single point

was calculated. This ratio which is the filter function of the difference output of two refractometers was examined.

Two models for the refractive index filter function were proposed. The first model assumes a frozen structure of the atmosphere moving with a constant wind. This model is of the form  $4 \sin^2(\pi fr/v)$ , where  $r$  is the refractometer spacing in meters,  $v$  is the wind speed in meters/second, and  $f$  is the frequency in Hz. The second proposed filter function model assumes a well mixed atmosphere with a variable wind. The form for the second model is  $2(1 - \sin(2\pi fr/v) / 2\pi fr/v)$  where the parameters are the same as in the first model.

Amplitude distributions were plotted on Gaussian probability paper and from these plots, along with observation of original difference data, an empirical probability density function is proposed. This proposed probability density function is the sum of three Gaussian functions. One of the Gaussian functions has a zero mean whereas the two other Gaussian functions have mean values of  $\pm a$ . The variance of the function with zero mean is about one-tenth that of the other two functions.

Refractive index structure function,  $D_n(r)$ , is defined as

$$D_n(r) = \overline{[n(r) - n(o)]^2},$$

where  $n(r)$  is the index of refraction at point  $r$  and  $n(o)$  is the index of refraction at the reference point  $o$ . The overbar denotes time average.

Measurements of refractive index difference suggest a duality in the mechanism causing the fluctuation of these data. The original difference data show spikes superimposed on a continuum of variations. These spikes are present but obscured in single unit refractive index data. Examination of amplitude probability distribution indicates one set of characteristics between approximately 5 per cent and 95 per cent points and another set of characteristics outside of these limits. The spikes make a major contribution to the structure function for separations below four meters.

Some characteristics of refractive index difference data were noted by observing paper strip chart recordings of the original data. Single unit refractive index changes tend to vary predominantly in the direction of increasing index. This indicates an enhancement of water vapor content in the atmosphere since the refractive index changes are influenced more by water vapor changes than by temperature changes.

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Allan B. Plunkett, "A Radar Design for Atmospheric Turbulence Studies," Report No. P-20, Antennas and Propagation Division, Electrical Engineering Research Laboratory, The University of Texas, 1 August 1967, 64 pages.

Abstract

Atmospheric turbulence can presently be measured only on the ground or by means of airplanes flying through the turbulent area. A properly designed radar system may be able to detect and analyze atmospheric turbulence from a position remote from the turbulent area. The choices of antenna, wavelength, transmitter power, receiver sensitivity, and detection methods are examined. The differences between pulse or cw and bistatic or monostatic systems are discussed. A comparison with existing radar systems used for atmospheric turbulence research is made.

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A. P. Deam, A. W. Straiton, J. L. Dodd, "Surface Refractive Index Differences at 14,250 Feet Elevation," Report No. P-22, Antennas and Propagation Division, Electrical Engineering Research Laboratory, The University of Texas, 30 November 1967, 14 pages.

Abstract

Surface refractivity at 14,250 feet elevation is reported in the form of difference measurements. Spectra, amplitude distributions, and structure functions are computed and included. Values of  $C_n^2$  may be inferred from the structure functions. The "frozen in" hypothesis is examined by comparing time spectra of the difference measurements with theoretical computations for this spectra. Structure functions at 14,250 feet (surface) are compared with those at 785 feet elevation (280 feet above surface).

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### Publications in Technical Journals

- J. J. Stephens and E. R. Reiter, "Estimating Refractive Index Spectra in Regions of Clear-Air Turbulence," Journal of Applied Meteorology, Vol. 6, No. 5, October 1967, pp. 911-913.

#### Abstract

Estimates of the spectrum of refractivity fluctuations to be expected in regions of clear-air turbulence are shown for scales in the inertial subrange. Based on the complete analysis by Atlas et al., it is concluded that radar detection of clear-air turbulence with current technology is unlikely for all but inversion conditions. However, the present analysis can be used to provide consistent estimates for particular environmental conditions.

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- A. W. Straiton, A. P. Deam, J. L. Dodd, "Amplitude Distributions of Refractive Index Differences," Journal of Geophysical Research, Vol. 72, No. 16, August 15, 1967, pp. 4051-4057.

#### Abstract

Measurements of refractive index differences suggest a duality in the mechanism causing the fluctuation of these data. The original difference data show spikes superimposed on a continuum of variations. These spikes are present but obscured in single unit refractive index data. Examination of amplitude probability distribution indicates one set of characteristics between approximately 5 and 95 per cent points and another set of characteristics outside of these limits. The spikes make a major contribution to the structure function for separations below 4 meters. It is suggested that the spikes may be due to the clustering of water vapor with a preferential volume size of a few meters and with a gradient of refractive index from the edge to the center of approximately one N-unit.

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- A. W. Straiton, A. P. Deam, J. L. Dodd, and B. M. Fannin, "Analysis of Spectra of Atmospheric Refractive Index Differences," Radio Science, January or February, 1968 (estimated 10 pages).

#### Abstract

When atmospheric refractive index is observed through the measurement of the index differences between two points, a filtering action is introduced in the fluctuation spectra. By dividing the refractive index difference spectra frequency component by the corresponding frequency component of

the index spectra for single-point data, a filter function is obtained. It is the purpose of this paper to examine this filter function by comparison of test results with theoretical models.

The measured filter functions for 12 samples of data, obtained with four refractometers on top of an 85 meter tower, are presented. These twelve cases are arranged in the order of increasing wind variability; that is, of increasing ratio of rms wind speed variation to the mean wind speed.

The measured data are compared with theoretical filter functions derived assuming a "frozen-atmosphere" model; a statistically homogeneous and isotropic invariant structure being assumed to be carried along at the mean wind velocity. A single mean wind velocity is assumed for those periods for which the measured wind data indicate a nearly constant flow. For more variable situations an integration over a range of mean wind speeds and wind directions is employed.

Though there are numerous marked differences between the measured and calculated filter functions (as would be expected whenever a crude model is used to predict results for a truly complex situation), the model assumed does provide satisfactory explanations for many of the observed features.

An unexplained anomaly which appears in the measured filter function for many of the cases is that at the high frequency end the functions are lower than predicted.